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Tentative Proposal for a Transistorized Communications Receiver Operating from 12 to 30 Mc.

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1. Technical Discussion

The following technical discussion briefly discusses the problems to be encountered and the techniques that might be incorporated in order to design a transistorized receiver which will operate over a band of frequencies from 12 to 30 Mc. For purposes of analysis it will be assumed that the over-all specifications pertaining to such a receiver will be similar to those of the RR-11AA Transistorized Communications Receiver.

Aspects of these specifications not specifically mentioned in the following sections are considered straight-forward and within the realm of definite practicality. The items mentioned are those that have major bearing on the best techniques to be incorporated and are mentioned as design problems difficult to solve or as yet not encountered.

1.1 Band Coverage

In order to tune the receiver over a frequency range of 12 to 30 megacycles, the tunable element must be varied by 6 ½:1. Because of the extremely high tuning accuracies required and the limited space available it is believed that inductive tuning is more adaptable for this application. Preliminary analysis indicates that it is possible to build an inductance tuner with greater accuracy and ruggedness and whose tolerances could be maintained more closely in production than would be possible in a ganged condenser tuner. This is primarily so due to the extremely small spacing that would be required between the condenser plates in order to build the tuner in a reasonably small volume. Moreover, the image and i.f. rejection specifications, as well as those of oscillator radiation, would be more difficult to meet with capacitive tuning at the frequencies in question.

It appears likely that the inductance range of 6 ½:1 required, may be accomplished in a single band. However, due to the fact that the permeability of the slugs is not as great as that which may be obtained at lower frequencies, and because coil distributed capacity and line inductance will be a relatively large percentage of the inductance value used, a slug travel in the order of 2¼" may be required. However, as indicated in further sections, this is not necessarily a disadvantage since other design criteria will dictate an increase in the over-all case length.

1.2 Calibration Accuracy and Resetability

The calibration accuracy specification of .1% and the resetability specification of .01% become increasingly difficult to obtain at these high frequencies. In order to provide good resetability the straight line frequency characteristic should not be obtained by a

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mechanical function generator as the main drive. Variable pitch coils offer a better possibility of obtaining linear frequency versus rotation in a highly accurate manner.

Consultations with various coil manufacturers reveal the fact that due to variation in winding tensions and incremental core permeabilities production coils cannot be wound with linearities in excess of 1%. Also to be considered are the non-linearities that will be introduced due to tolerances of circuit components and the mechanical drive. Therefore, if the calibration accuracy is to be obtained, it will be necessary to design a system which will permit multi-point tracking. Correction will be required for the oscillator circuit only, since a linearity of 1% will be more than adequate for the coils in the signal path.

A technique which offers good possibilities of achieving the desired end result in a relatively simple manner involves a cam follower mechanism. A spring loaded roller rigidly linked to the oscillator core would be guided up or down by means of a flexible metal bar. This would permit an incremental increase or decrease of inductance depending on the contour of the bar at the particular point of carriage travel. Six to eight tracking studs could be utilized to achieve the contour required to permit cancellation of the predominant non-linearities.

The basic mechanical drive system would be kept simple to insure high accuracy and good resetability. The tuner would consist of a chassis for rigid mounting of the coils and a carriage containing the coil slugs. Carriage motion would be achieveddby means of a fine pitch screw incorporating an anti-back lash mechanism. A vernier scale would be directly linked to the fine pitch screw and geared by the proper ratio to the main scale.

1.3 R. F. Design Criteria

In order to design a transistorized receiver which will operate at frequencies as high as 30 Mc., two factors take on primary importance; i.e., the characteristics of transistors, and the Q of the coils which are available at the present time. The present state of the art of these components and their bearing upon system design will be discussed in the following paragraphs.

1.3.1 Sensitivity.—The surface barrier transistor and possibly selected junction tetrode transistors are the only types which have any possibility for this application. The junction tetrode transistor required 5 to 10 times as much power for its operation as the SBT, have poor availability, and many other disadvantages, which preclude their use. Therefore, this discussion will be based upon the best design techniques that could be incorporated utilizing the surface barrier transistors.

There are 3 inter-related parameters that must be considered

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in determining whether a transistor will be suitable for the application under discussion; they are 1) the product of the collector capacity and base spreading resistance (rb'Cc); 2) the alpha cutoff frequency Fc α; and 3) the maximum frequency of oscillation F_{max}. F_{max} is related to alpha cutoff frequency and the rb'Cc product by the following equation.

$$f_{max} = \sqrt{\frac{\alpha o \, Fc\alpha}{8\pi \, rb'Cc}}$$

The gain that a transistor will have at frequencies other than F_{max} is related to F_{max} by the following relationship.

$$\text{Unilateral Power Gain} = \left(\frac{F_{max}}{f}\right)^2$$

In order that the noise problems be kept within realizable limits, the gain of the r.f. amplifier including coil losses should be greater than 1, so that the signal at the input to the next stage will not be attenuated. If, for purposes of analysis, it is assumed that 3 db of coil losses are present in both the input and output transformers, and an additional 3 db of attenuation results due to the neutralization process, the transistor must have a power gain of at least 9 db in order for the r.f. amplifier to have an over-all gain of unity. From the above relationship it can be seen that F_{max} must be at least 90 Mc. In terms of the parameters on which transistor characteristics are generally specified, for an rb' = 250 ohm (normal for most transistors), Cc must be less than 3 uufd and Fcα must be greater than 120 Mc. Except for the surface barrier transistor, no commercially available transistor approaches these requirements.

Examination of distribution curves of the present L5106 surface barrier transistors now in production reveals that approximately 20 to 25% of production units would be acceptable. It is anticipated that transistors now in the research phase will be available in the foreseeable future that will have considerably higher values of F_{max}. However, the following analysis of the basic system parameters will be based on present manufactured components.

1.3.2 <u>Image and R. F. Rejection</u>.—A preliminary investigation indicates that at 30 Mc. the highest coil Q of an air inductance (slug completely out at 30 Mc.) with materials now available would be in the order of 30 to 40. Assuming 36 as a design center value and limiting core losses to 3 db in its tuned circuit, the over-all circuit Q should not exceed 18. Under these conditions, a neutralized r.f. amplifier will have a gain of unity for a transistor gain of 9 db at 30 Mc. If the i.f. frequency were to be 455 kc., approximately 9 tuned stages would be required to get an image rejection of 30 db at 30 Mc. Such operation is clearly impractical

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due to the very difficult tracking problems that would exist, the extremely complex tuner required and the great number of components that must be incorporated. Therefore, it is felt that the i.f. frequency cannot possibly be 455 kc.

In order to keep equipment complexity to a minimum an analysis will be made of the lowest i.f. frequency that would be required utilizing only two tuned circuits in the signal path prior to conversion. This will permit tracking with three tunable slugs, i.e., one for the oscillator, one for the r.f. amplifier input, and one for the amplifier output. With a circuit Q of 18, the image rejection specification can be met at 30 Mc. if the image frequency is 5 Mc. or more above the 30 Mc. input. Since the highest frequency will be the worst case, the i.f. frequency should be at least 2.5 Mc.

1.4 Optimum I. F. Frequency

From the foregoing analysis it can be seen that the image rejection cannot be met with two tuned stages unless the i.f. frequency is $2\frac{1}{2}$ Mc. or greater. The ability to meet other related specifications in a similar number of stages such as oscillator radiation, spurious responses, and i.f. rejection also are dependent upon the i.f. frequency chosen.

The over-all selectivity specifications cannot be met in a practical manner by any method other than a mechanical filter. These filters are available only at a few selected frequencies, none of which are greater than 2.5 Mc. Therefore, a non-standard item must be procured which would involve initial development costs in the order of $30,000. Another less severe objection to an i.f. frequency of $2\frac{1}{2}$ Mc. or higher is the fact that an additional i.f. stage would be required since each of the 3 i.f. amplifiers would have about 6 db less gain than could be realized at 455 kc.

1.4.1 Double Conversion System.-All of the above objections to an i.f. frequency of 455 kc. or an i.f. frequency of $2\frac{1}{2}$ Mc. or greater can be overcome by means of a double conversion system. The first i.f. frequency is selected to be $2\frac{1}{2}$ Mc. or greater and then converted to a frequency of 455 kc. The major part of the i.f. amplification would occur at 455 kc. which is below the gain cross-over point for a grounded emitter surface barrier transistor. One possible disadvantage to this scheme is that spurious responses would be somewhat harder to predict and design for. However, inherently this system should not be more conducive to spurious responses than that of a single i.f. frequency.

1.5. Proposed Receiver Design

An analysis of the discussion in the preceding sections indicates that a double conversion system presents the best possibilities in an attempt to meet the specifications outlined. A block diagram of the proposed tuner design is shown in Figure I. The signal levels and the frequency of operation are indicated at the various points of interest.

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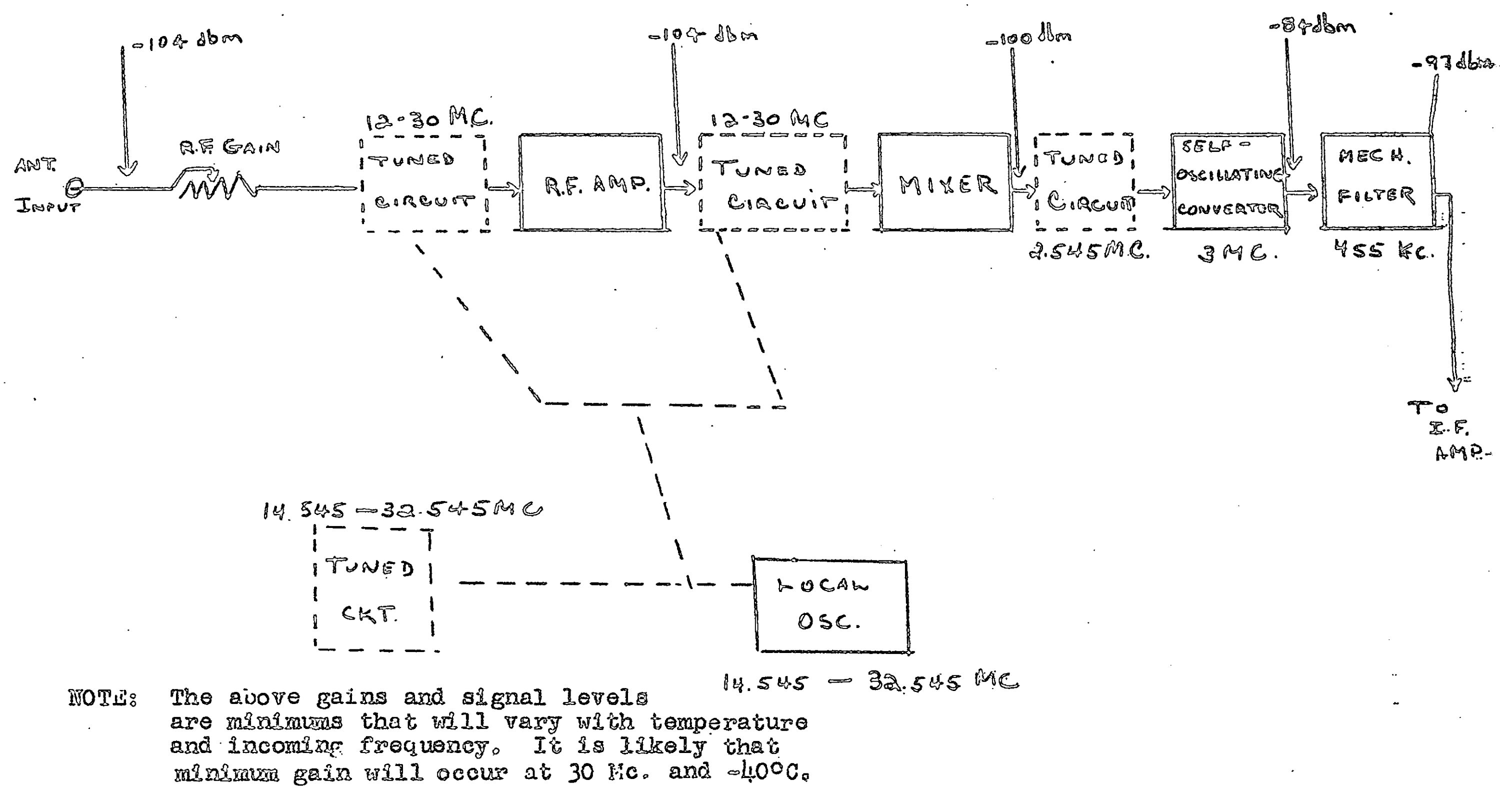

NOTE: The above gains and signal levels are minimums that will vary with temperature and incoming frequency. It is likely that minimum gain will occur at 30 Mc. and -40°C.

TUNER BLOCK DIAGRAM

FIGURE 1

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The r.f. amplifier will not contribute to system over-all gain. Its main purposes are to provide image and i.f. rejection, cut down oscillator radiation, provide selectivity to reduce spurious responses, and minimize oscillator pulling. The local oscillator frequency will be set at 2½ Mc. or greater above the incoming frequency and will be injected into the mixer circuit. The output circuit of the mixer will be tuned to select the difference frequency generated (hereafter referred to as the 1st i.f. frequency). The mixer will provide approximately 4 db of gain at 30 Mc. utilizing a transistor with an F_{max} of 90 Mc. The mixer output will then be fed into a self-oscillating converter. This converter circuit will be fixed tuned with the oscillator frequency being set at 455 kc. above the 1st i.f. frequency. If space requirements permit and if an improvement in over-all operation results the self-oscillating frequency could be crystal controlled. Since the 1st i.f. frequency is relatively close to the low frequency cutoff of the transistor, gains in the order of 16 db or more could be experienced. The over-all gain therefore will be sufficient to insure that the 13 db loss of mechanical filter will be overcome and that the signal to the 1st i.f. amplifier will be appreciably above the noise level of the r.f. amplifier.

1.5.1 R. F. Amplifier.-The input signal to the r.f. amplifier will be fed from the antenna through an r.f. gain control. This control will assure that overloading will not occur in any of the tuner circuits on large signals. It is not advisable to control the gain of the tuner circuits themselves because frequency pulling and calibration accuracy would suffer. It is absolutely necessary to neutralize the internal feed-back within the transistor at these frequencies in order to preventoscillation, permit simple tuning, and to keep the reverse gain low in order to meet the oscillator radiation specifications. The neutralizing capacitor for this application must be adjustable so as to allow for precise adjustment because of the large amount of internal feed-back that could be experienced at the high frequencies.

The input impedance of the r.f. amplifier will be stepped up by capacitors across the tuned circuit to allow for optimum Q and still provide a nominal input impedance of 300 ohm when maximum sensitivity is required. The output of the tuned circuit will be stepped down to allow for best power match into the lower impedance at input of the r.f. amplifier.

A small capacitor will be used for coupling to the mixer circuit which would provide best power match at 30 Mc. and a proportionately larger mismatch at lower frequencies. This will tend to keep the mixer gain constant over the frequency range since the gain of the mixer circuit proper will decrease at the rate of 6 db per octave over the frequencies increased. Additional advantages of coupling by a small capacitor is the reduction in oscillator radiation and the improvement in i.f. rejection. The time constant will be sufficiently low so that there will be no possibility of blocking on large signals.

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1.5.2 Mixer.—The output of the mixer will be tuned to the 1st i.f. with a fairly high Q circuit to minimize the possibilities of spurious responses being passed. The mixer will be a grounded base transistor with no provision for neutralization since the signal developed at its output will be at a different frequency from the local oscillator andthe incoming signal.

1.5.3 Local Oscillator.—The local oscillator will be a grounded base transistor with an F_{max} in the order of 90 Mc. It will be connected as a colpitts oscillator with its feed-back obtained by means of a capacity divider. A tap on the coil is not practical, since the inductance of the tap as compared to the total inductance will vary quite radically over the tuning range utilizing a variable pitch coil. The local oscillator output will be coupled to the mixer through the secondary of the variable pitch transformer. The secondary will be wound in a manner which will tend to aid the high frequency response.

1.5.4 Self-Oscillating Converter.—The converter can be made self-oscillating by tuning the output circuit to both the oscillator frequency and the beat frequency produced and feeding back the oscillator signal to the emitter as shown in Figure 5. With this technique, conversion gains of 16 db or greater can be obtained at the input frequency of $2\frac{1}{2}$ Mc. It is advisable for this particular stage to have a high alpha cutoff since the input impedance to the r.f. signal in proportion to ($\frac{1}{1-\alpha}$) which begins to decrease at frequencies of Fc $(1-\alpha)$.

1.6 Frequency Stability and Oscillator Pulling.

Frequency stability of .0004% per minute specified will be a very serious problem at frequencies as high as 30 Mc. The higher the frequency the more the possibility of drift because of the larger effect of transistor variations. Since no information is available concerning the drift that may be experienced the stability requirements must be held as design goals rather than absolute specifications.

The frequency pulling specification of 100 cycles from minimum to maximum signal is another specification upon which no definite statement can be made regarding compliance. Best techniques should be incorporated, such as having gain variation take place in the r.f. input potentiometer and the i.f. amplifier rather than in the r.f. amplifier or the conversion circuits. Even with these precautions this specification may be quite difficult to meet and should therefore be considered a design goal rather than an absolute specification.

1.7 Space and Weight Limitations

In order to allow packaging of the additional components that

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would be required in the 12 to 30 Mc. tuner, in a manner which will insure best electrical performance the over-all case length should be increased at least 3/4's of an inch to a total of 7 inches. This additional length will be needed because of the larger number of components that are required and the larger carriage travel that may be necessary.

It is also felt that it will be impossible to achieve packaging in the over-all volume anticipated unless tantalytic capacitors are utilized. A large pool of information exists within the Philco organization on these capacitors, so that they may be incorporated strategically with no reduction in electrical performance.

1.8 Interchangability with the RR-11AA Receiver

One of the most important advantages of the double conversion system is the fact that the receiver from the input to the mechanical filter to the input of the earphones could be made identically in every respect with that being developed for the RR-11AA Receiver. This type of operation would undoubtedly result in a large saving both in development and production costs of the 12 to 30 Mc. receiver. A further saving in cost and a possible operational advantage would result if a single receiver covering the band of frequencies from 3 to 30 Mc. could beobtained simply by interchanging the tuner and using the common i.f. audio portion of the receiver.

Basic packaging philosophy to date on the RR-11AA receiver could well make this practical since present plans and designs call for a separately testable tuner assembly which would mount into the case and would receive power through a plug-in cable. The electronic chassis, with all associated controls and connectors, would contain all of the other circuitry including batteries and would be mounted to the case cover. Of course, this type of operation would require an increase in the length of the case of the RR-11AA receiver to accommodate the larger tuner for the band from 12 to 30 Mc. It also may be found that the length of theRR-11AA receiver may have to be increased to accommodate the slug travel necessary to provide the range of frequency adjustment in single band operation.

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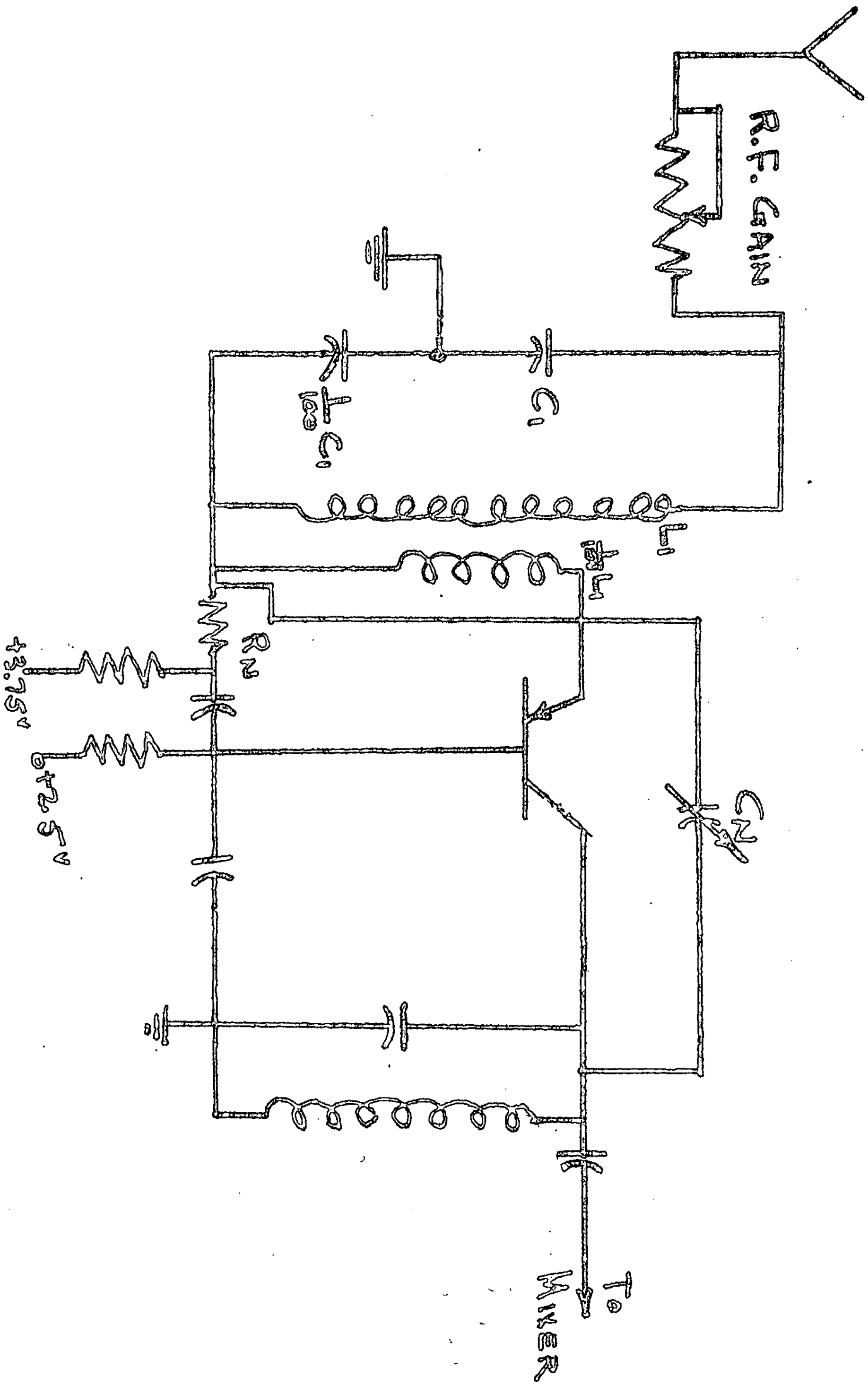

Fig. 2 - Proposed RF Amplifier.

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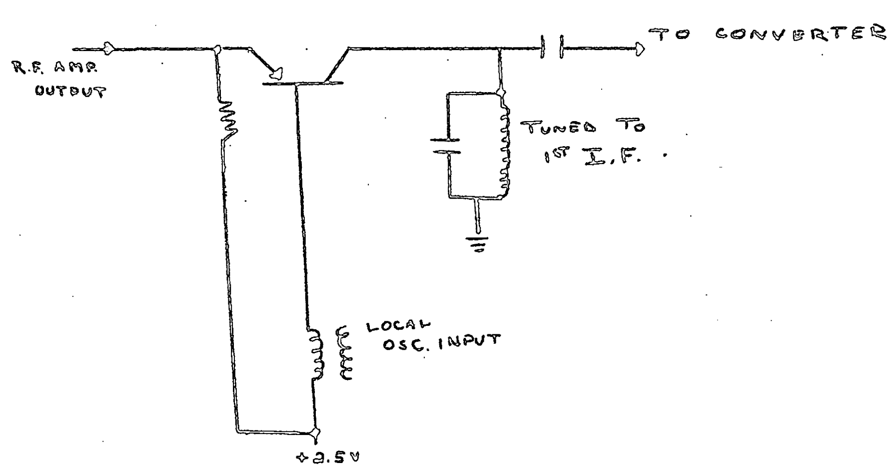

PROPOSED MIXER
FIGURE 3

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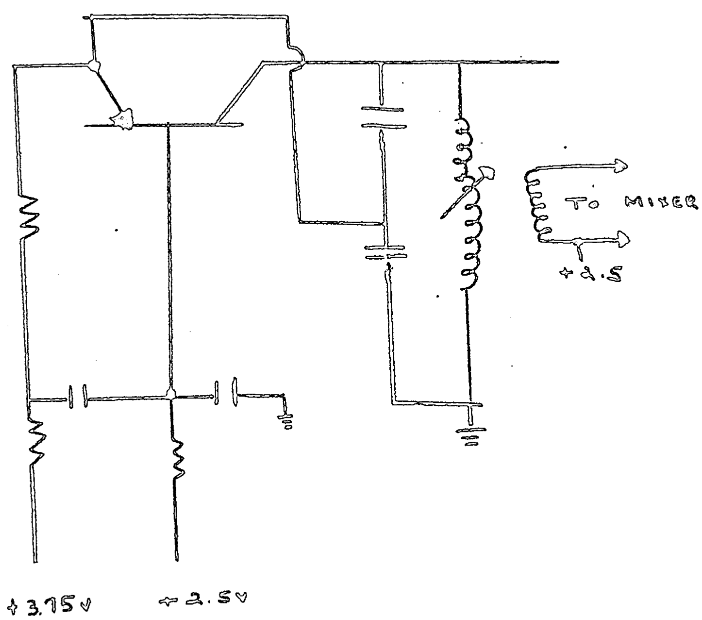

PROPOSED LOCAL OSCILLATOR

FIGURE 4

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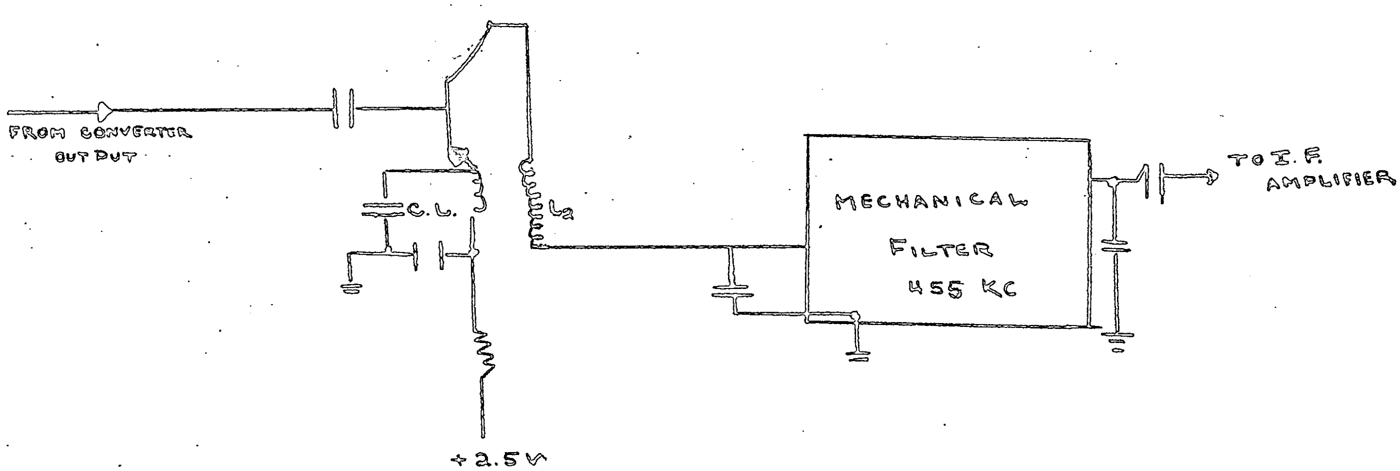

SELF OSCILLATING CONVERTER
FIGURE 5

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TRANSISTOR RECEIVER
RR-11AA

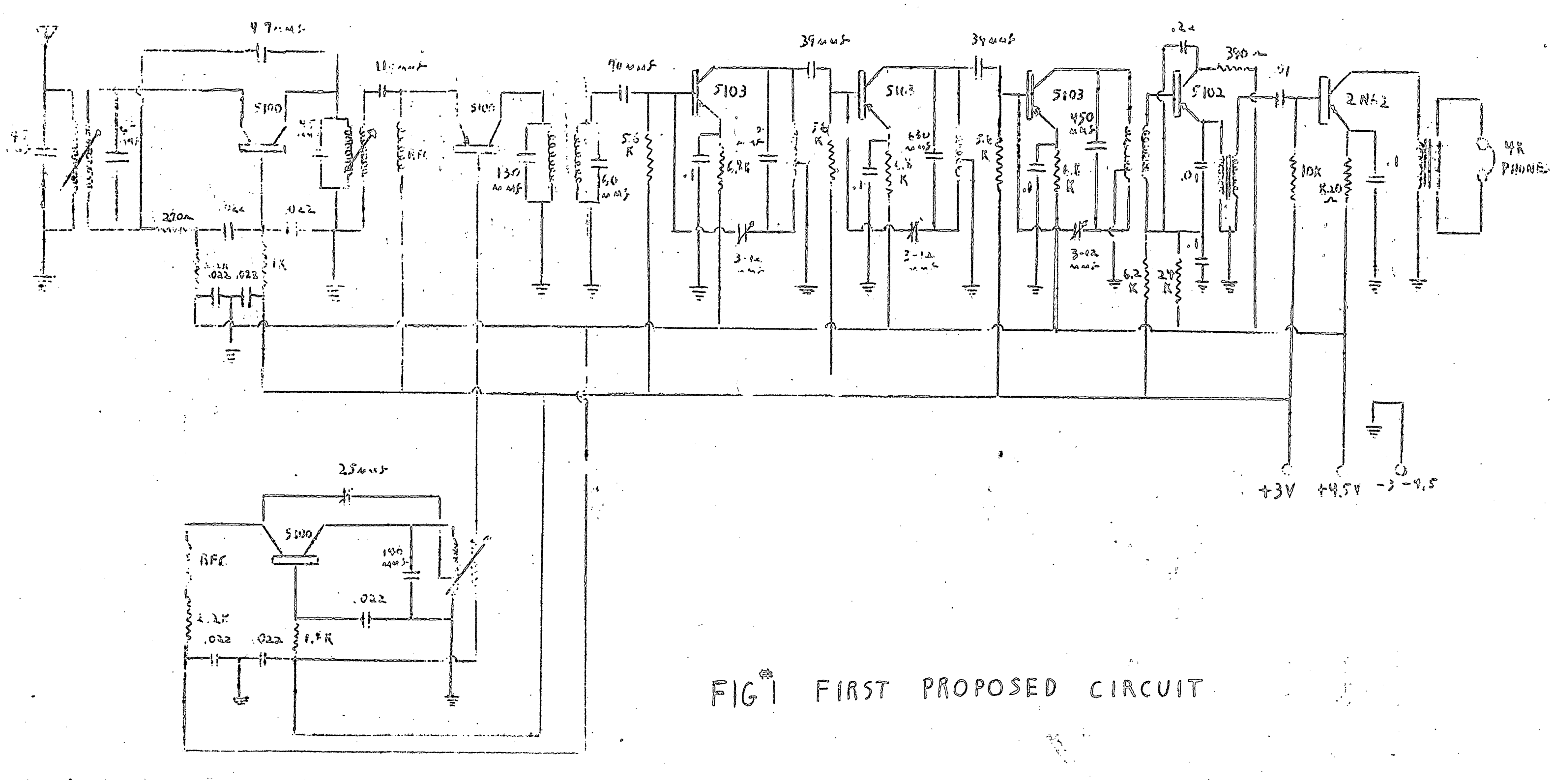

FIG 1 FIRST PROPOSED CIRCUIT

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